

Deeply Virtual Compton Scattering with CLAS12.

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An overview is given about the capabilities provided by the JLab 12 GeV Upgrade to measure deeply virtual exclusive processes with high statistics and covering a large kinematics range in the parameters that are needed to allow reconstruction of a spatial image of the nucleon's quark structure. The measurements planned with CLAS12 will cross section asymmetries with polarized beams and with longitudinally and transversely polarized proton targets in the constrained kinematics $x = \pm\xi$. In addition, unpolarized DVCS cross sections, and doubly polarized beam target asymmetries will be measured as well. In this talk only the beam and target asymmetries will be discussed.

Keywords: GPDs, DVCS

1. Introduction

The concept of GPDs¹⁻³ has led to completely new methods of “spatial imaging” of the nucleon. The mapping of the nucleon GPDs, and a detailed understanding of the spatial quark distribution of the nucleon, have been widely recognized as a key objectives of nuclear physics of the next decade, and is a key justification for the JLab energy upgrade to 12 GeV. GPDs also allow to quantify how the orbital motion of quarks in the nucleon contributes to the nucleon spin – a question of crucial importance for our understanding of the “mechanics” underlying nucleon structure. This requires a comprehensive program, combining results of measurements of a variety of processes in electron–nucleon scattering with structural information obtained from theoretical studies, as well as with expected results from future lattice QCD simulations.

It is well recognized⁴⁻⁶ that exclusive processes can be used to probe the GPDs and construct 2-dimensional and 3-dimensional images of the quark content of the nucleon. Deeply virtual Compton scattering and deeply virtual meson production are identified as the processes most suitable to

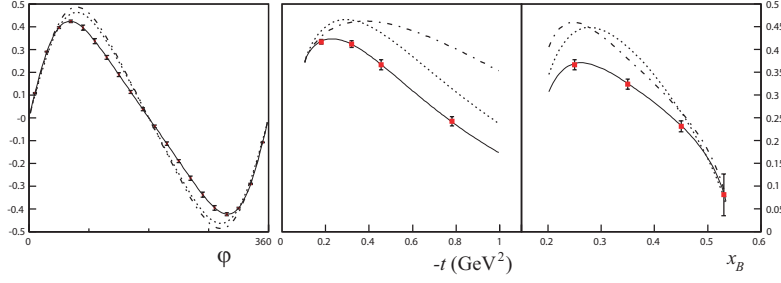


Fig. 1. The beam spin asymmetry showing the DVCS-BH interference for 11 GeV beam energy from the VGG model¹⁴ with uncertainties projected for 11 GeV.¹³ Many other bins will be measured simultaneously.

map out the twist-2 vector GPDs H , E and the axial GPDs \tilde{H} , \tilde{E} in x , ξ , t , where x is the momentum fraction of the struck quark, ξ the longitudinal momentum transfer to the quark, and t the momentum transfer to the nucleon. Having access to a 3-dimensional image of the nucleon (two dimensions in transverse space, one dimension in longitudinal momentum) opens up completely new insights into the complex structure of the nucleon. For example, the nucleon matrix element of the energy-momentum tensor contains 3 form factors that encode information on the angular momentum distribution $J^q(t)$ of the quarks with flavor q in transverse space, their mass-energy distribution $M_2^q(t)$, and their pressure and force distribution $d_1^q(t)$. These form factors also appear as moments of the vector GPDs,⁷ thus offering prospects of accessing these quantities through detailed mapping of GPDs. The quark angular momentum in the nucleon is given by

$$J^q(t) = \int_{-1}^{+1} dx x [H^q(x, \xi, t) + E^q(x, \xi, t)] ,$$

and the mass-energy and pressure distribution

$$M_2^q(t) + 4/5 d_1^q(t) \xi^2 = \int_{-1}^{+1} dx x H^q(x, \xi, t) .$$

The mass-energy and force-pressure distribution of the quarks are given by the second moment of GPD H , and their relative contribution is controlled by ξ . The separation of $M_2^q(t)$ and $d_1^q(t)$ requires measurement of these moments in a large range of ξ .

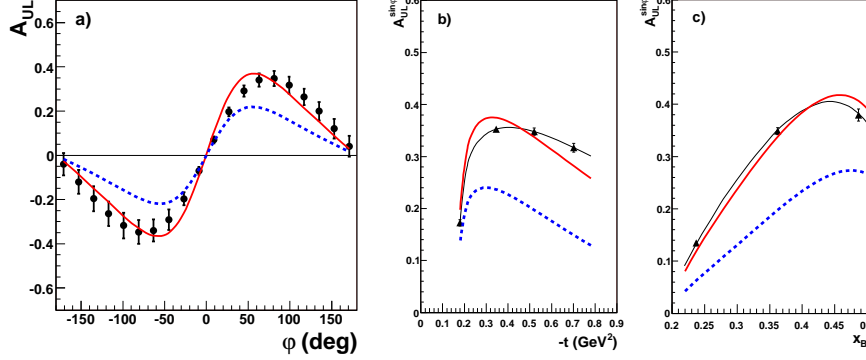


Fig. 2. The longitudinal target spin asymmetry beam spin asymmetry showing the DVCS-BH interference for 11 GeV beam energy from the VGG model¹⁴ with uncertainties projected for 11 GeV.¹³ Other bins will be measured simultaneously

2. GPDs and DVCS

DVCS has been shown^{8–11} to be the cleanest process to access GPDs at the kinematics accessible today. It is also a relatively rare process and requires high luminosities for the required high statistics measurements. The beam helicity-dependent cross section asymmetry is given in leading twist as

$$A_{LU} \approx \sin \phi [F_1(t)H + \xi(F_1(t) + F_2(t))\tilde{H}]d\phi ,$$

where F_1 and F_2 are the Dirac and Pauli form factors, ϕ is the azimuthal angle between the electron scattering plane and the hadronic plane. The kinematically suppressed term with GPD E is omitted. For not too large ξ the asymmetry is mostly sensitive to the GPD $H(x = \xi, \xi, t)$.

The asymmetry with a longitudinally polarized target is given by

$$A_{UL} \approx \sin \phi [F_1(t)\tilde{H} + \xi(F_1(t) + F_2(t))H] .$$

The combination of A_{LU} and A_{UL} allows a separation of GPD $H(x = \xi, \xi, t)$ and $\tilde{H}(x = \xi, \xi, t)$.

Using a transversely polarized target the asymmetry

$$A_{UT} \approx \sin \phi t / 4M^2 [F_2(t)H - F_1(t)E]$$

can be measured, which depends in leading order on GPD E and is highly sensitive to orbital angular momentum contributions of quarks.

Clearly, determining moments of GPDs for different t will require measurement in a large range of x , in particular at large x . The reconstruction

of the transverse spatial quark distribution requires measurement in a large range in t , and the separation of the $d_1^q(t)$ and $M_2^q(t)$ form factors requires a large span in ξ .

3. Upgrade of CLAS to CLAS12.

To meet the requirements of high statistics measurements of relatively rare exclusive processes such as DVCS at high photon virtuality Q^2 , large t and ξ , the CLAS detector will be upgraded and modified to CLAS12.¹⁶ The main new features of CLAS12 over the current CLAS detector include a high operational luminosity of $10^{35}\text{cm}^{-2}\text{sec}^{-1}$, an order of magnitude increase over CLAS.¹⁵ Improved particle identification will be achieved with additional threshold gas Cerenkov counter, improved timing resolution of the forward time-of-flight system, and a finer granularity electromagnetic preshower calorimeter that, in conjunction with the existing CLAS calorimeter will provide much improved γ/π^0 separation for momenta up to 10 GeV. In addition, a new central detector will be built that uses a high-field solenoid magnet for particle tracking and allows the operation of dynamically polarized solid state targets. With these upgrades CLAS12 will be the workhorse for exclusive electroproduction experiments in the deep inelastic kinematics.

4. Projected results at 12 GeV with CLAS12.

The 12 GeV upgrade offers much improved capabilities to access GPDs. Figure 1 shows the expected statistical precision of the beam DVCS asymmetry for some sample kinematics. At the expected luminosity of $10^{35}\text{cm}^{-2}\text{sec}^{-1}$ and for a run time of 2000 hours, high statistics measurements in a very large kinematics range are possible.

Using a dynamically polarized NH_3 target we can also measure the longitudinal target spin asymmetry A_{UL} with high precision. The projected results are shown in Fig. 2. The statistical accuracy of this measurement will be less than for the A_{LU} asymmetry due to the large dilution factor in the target material, but it will still be a very significant measurement.

Polarizing the target transverse to the beam direction will access a different combination of GPDs, and provide different sensitivity for the y- and x-components of the target polarization. The expected accuracy for one of the polarization projections is shown in Fig. 3. Here the target is assumed to be a frozen HD-Ice target, which has different characteristics from the NH_3 target.

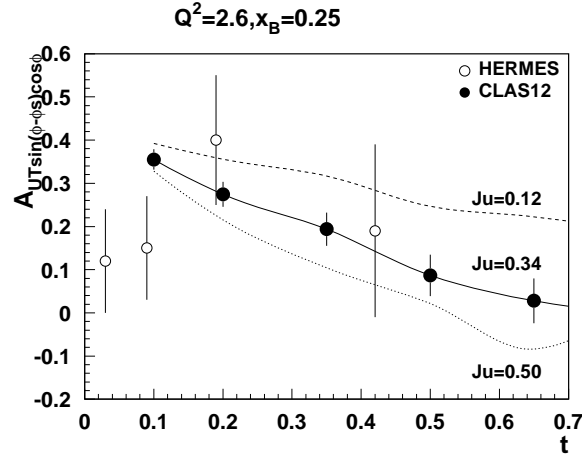


Fig. 3. Projected transverse target asymmetry A_{UT} for DVCS production off protons at 11 GeV beam energy. The curves represent different assumptions on the u-quark contributions to $J(t)$.

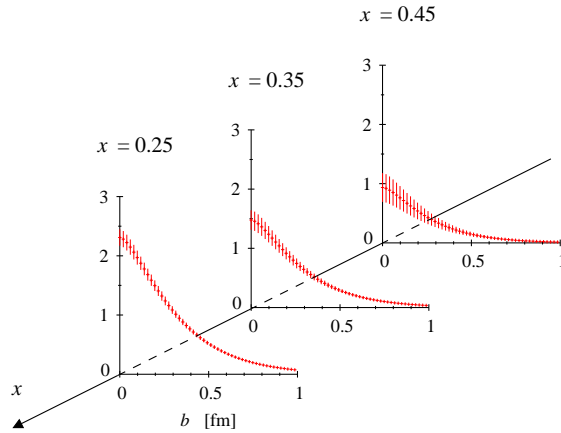


Fig. 4. The u-quark distribution in transverse space as extracted from projected DVCS data with CLAS12.

A measurement of all 3 asymmetries will allow a separate determination of GPDs H , \tilde{H} and E at the above specified kinematics. Through a Fourier transformation the t -dependence of GPD H can be used to determine the

u -quark distribution in transverse impact parameter space. Figure 4 shows projected results for such a transformation assuming a model parameterization for the kinematical dependences of GPD H . Knowledge of GPD E will be particularly interesting as it is directly related to the orbital angular momentum distribution of quarks in transverse space.

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